LEARNING LESSONS THE (NOT QUITE SO) HARD WAY INCIDENTS, THE ROUTE TO HUMAN FACTORS

IN ENGINEERING

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I want to draw attention to a number of Incidents which have fired my interest in Human Factors in Engineering.

I am not a psychologist or a physiologist and cannot claim to be a 'Human Factors Expert'. I am however, and have been for a number of years a government air accident investigator, regularly called upon to fulfill the role of Investigator-in-Charge of a wide variety of accident and incident investigations.

WHY HUMAN FACTORS?

As an industry we are inclined to boast about our safety record, and in many respects history supports our claims. This record has been achieved through close attention to detail in design, manufacture, maintenance and operating standards, where practices have often been characterised by conservative factors of safety. When it has gone wrong and an accident resulted, meticulous investigation has often identified a visible cause and the lesson has been learnt. By this process many types of accident have been 'squeezed' out of the system. Having eliminated some of the more obvious causes of accidents we are left with those causes that are more difficult to identify and address. Consequently, in recent years the accident rate has remained reasonably constant.. It appears to be generally accepted that 70-80% of accidents are now attributable directly to human failing in the operation of the aircraft.

The Department of Transport 1991 Air Traffic forecasts for the United Kingdom include forecasts of annual traffic growth rates up to the year 2005.

> Air traffic passenger movements at UK airports is expected to increase by between 75% in the low economic growth scenario and 145% in the high economic growth scenario over the period. These figures are consistent with an annual growth rate over the period 1989 to 2005 of between 3.5% and 5.8%.

These forecasts agree well with a paper produced by the Boeing Airplane Co. and published in 'Aerospace', the journal of the Royal Aeronautical Society, in July 1990 which stated:-

> The world-wide fleet of transport aircraft (excluding the USSR) is expected to handle a passenger growth rate of 5.5% a year. By the year 2005 the existing fleet of over 8,200 aircraft will grow to over 14,700. If the accident rates for the last 20 years are used to forecast the future, annual hull loss could increase from 14 to 20 or there will be a hull loss about every 20 days instead of the current 28 days.

The combination of a constant accident rate and a steady increase in air traffic movements inevitably results in an increasing number of accidents to be investigated.

A study of the total number of civil aircraft accidents occurring in the UK during the last 10 years shows annual rates in the range 180 to 307. Although there are considerable annual fluctuations the trend is for a steady and significant increase in the number of reportable accidents. 1990 was a record year with the 300 mark being passed for the first time, since then we have consistently passed that figure! If, as currently, up to 80% of the accidents are directly attributable to human failing, that is why the Human Factors investigation concerns me so!

WHY ENGINEERING?

The June edition of the RAeS Journal Aerospace stated that the number of 'Maintenance Concern' accidents is on the increase and that over the preceding 10 years whilst the number of flights had increased by 55% the number of 'Maintenance Concern' accidents had increased by 100%.

Human factor related causes to accidents are not restricted to the flight-deck. I have heard the argument that it is only in the cockpit that actions and results are closely linked in 'real time' and consequently human factors are of little or no consequence elsewhere. If a mechanic completes a task operating alone and is delegated the authority to 'sign off' the work, against a background of time pressure with minimum resources of tooling and supplies, and in a physically uncomfortable environment he is unlikely to give of his best. If the results of his work then go without functional or independent inspection until the aircraft is airborne, any error can result in an in-flight incident or worse. Does it matter that his actions and the final consequences are separated in time by hours, even days, if in that intervening period there was no attempt or opportunity to discover the mistake? Time was real enough throughout the task for the individual and only a sterile period separates cause and effect.

An acceptance that human factors have relevance outside the flight-deck has led to expansion of the Confidential Human Factors Incident Reporting Programme (CHIRP) in the UK to accept reports from air traffic controllers and there are imminent moves to include engineers even though there are some significant opponents.

At the start of this paper I referred to a number of incidents which had fired and continue to stimulate my interest in this area. I outline three of them below:-

BAC One-Eleven over Oxfordshire, 10 June 1990.

The accident happened when the aircraft was climbing through 17,300 feet on departure from Birmingham International Airport en route for Malaga, Spain. The left windscreen, which had been replaced prior to the flight, was blown out under effects of the cabin pressure when it overcame the retention of the securing bolts, 84 of which, out of a total of 90, were of smaller than specified diameter. The commander was sucked halfway out of the windscreen aperture and was restrained by cabin crew whilst the co-pilot flew the aircraft to a safe landing at Southampton Airport.

The following factors contributed to the loss of the windscreen:-

- A safety critical task, not identified as a 'Vital Point', was undertaken by one individual who also carried total responsibility for the quality achieved and the installation was not tested until the aircraft was airborne on a passenger carrying flight.

- The Shift Maintenance Manager's potential to achieve quality in the windscreen fitting process was eroded by his inadequate care, poor trade practices, failure to adhere to company standards and use of unsuitable equipment, which were judged symptomatic of a longer term failure by him to observe the promulgated procedures.

- The British Airways local management, Product Samples and Quality Audits had not detected the existence of inadequate standards employed by the Shift Maintenance Manager because they did not monitor directly the working practices of Shift Maintenance Managers.

Features of the windscreen change

- Short staffing - Night shift of 7 down by 2.

- Shift Manager does job himself and alone (10 years RAF 23 years BA - exemplary record).

- The A/C was remote and took the Shift Manager away from the location of his other duties.

- Time pressures - the morning shift was short staffed - aircraft was programmed for a wash.

- The task was conducted between 0300-0500 hrs - a time of Circadian lows.

- Shift Manager was on his 1st night work for 5 weeks.

- The Maintenance Manual was only used to confirm that the Job was ‘straight forward’.

- The IPC was not used. - the IPC was misleading.

- Shift Manager assumed the bolts fitted were correct - incorrect bolts fitted 4 years before.

- Shift Manager chose bolts by physical matching - main stores below minimum stock level.

- Shift Manager ignored the advice of the storeman on bolt size.

- Shift Manager got bolts from uncontrolled AGS Carousel with faded labels in dark corner.

- Shift Manager did not use his reading glasses at any time.

- Shift Manager arbitrarily increased the torque from 15 lb ft to 20 lb ft.

- Shift Manager didn't notice excessive countersinking or next window was different.

- The safety raiser used provided poor access.

- Shift Manager failed to recognise difference in torque when fitting the corner fairing.

- Shift Manager rationalised the use of different bolts next night when doing a similar job.

Was this Just one reckless individual?

What had happened to QA - what was the organizational Culture - what was the effect of internal and CAA Audits.

Airbus A320-212, Gatwick, 26 August 1993.

The incident occurred when, during its first flight after a flap change, the aircraft exhibited an undemanded roll to the right on takeoff, a condition which persisted until the aircraft landed back at London Gatwick Airport 37 minutes later. Control of the aircraft required significant left sidestick at all times and the flight control system was degraded by the loss of spoiler control.

The investigation identified the following causal factors:

- During the flap change compliance with the requirements of the Maintenance Manual was not achieved in a number of directly relevant areas:-

During the flap removal the spoilers were placed in maintenance mode and moved using an incomplete procedure, specifically the collars and flags were not fitted.

The re-instatement and functional check of the spoilers after flap fitment were not carried out.

- A rigorously procedural approach to working practices and total compliance with the Maintenance Manual was not enforced by local line management.

- The purpose of the collars and the way in which the spoilers functioned was not fully understood by the engineers. This misunderstanding was due in part to familiarity with other aircraft and contributed to a lack of adequate briefing on the status of the spoilers during the shift handovers.

- During the independent functional check of the flying controls the failure of spoilers 2 to 5 on the right wing to respond to right roll demands was not noticed by the pilots.

- The operator had not specified to its pilots an appropriate procedure for checking the flight controls.

Features of the Flap change

- LAE and team were new to the task.

- LAE was A320 authorised but the aircraft were rarely seen, this was 3rd party work.

- Planning was limited to a job card, change the flap, and provision of some special tooling.

- Maintenance Manual, A/C Maintenance Task oriented support system (AMTOSS) format.

- Tooling supplied was deficient or incorrect - no collars for locking spoiler.

- The LAE requested additional experienced help - none available.

- Other tasks were tackled during tooling delays and there were changes in task allocation.

- Task was carried out during the early hours, a time of Circadian lows.

- Team attempted to remove flap without disabling spoilers but couldn't.

- Spoilers were disabled without collars or flags, a deviation from Maintenance Manual.

- Shift hand over verbal, paperwork incomplete, hence misunderstanding over spoilers.

- Spoilers were pushed down during flap rigging.

- Familiarity with Boeing aircraft where spoilers auto reset.

- Flaps were functioned, the spoilers were not - a deviation from the Maintenance Manual.

- Duplicates were lead by day shift engineer.

- Failure to follow Maintenance Manual.

- During flight crew Walk round there was nothing amiss to see.

- Pre-flight check, 3 seconds mismatch control/surface position required to generate warning.

- Engineers demonstrated a willingness to work around problems without reference to design authority - including deviations from Maintenance Manual.

Boeing 737-400, Overhead Daventry, 23 February 1995

The incident occurred when the aircraft was climbing to cruise altitude after a departure from East Midlands Airport en-route for Lanzarote Airport in the Canary Islands. Following an indicated loss of oil quantity and subsequently oil pressure on both engines, the crew diverted to Luton Airport; both engines were shut down during the landing roll. The aircraft had been subject to Borescope Inspections on both engines during the night prior to the incident flight. The High Pressure (HP) rotor drive covers, one on each engine, had not been refitted, resulting in the loss of almost all of the oil from both engines during flight. There were no injuries to any crew or passengers. The aircraft was undamaged; both engines were removed and examined as a precautionary measure.

The investigation identified the following causal factors:-

- The aircraft was presented for service following Borescope Inspections of both engines which had been signed off as complete in the Aircraft Technical Log although the HP rotor drive covers had not been refitted.

- During the Borescope Inspections, compliance with the requirements of the Aircraft Maintenance Manual was not achieved in a number of areas, most importantly the HP rotor cover drive covers were not refitted. and ground idle engine runs were not conducted after the inspections.

- The Operator's Quality Assurance Department had not identified the non-procedural conduct of Borescope Inspections prevalent amongst Company engineers over a significant period of time.

- The Civil Aviation Authority, during their reviews of the ‘Company Procedures’ for JAR-145 approval, had detected limitations in some aspects of the Operator’s Quality Assurance system, including procedural monitoring, but had not withheld that approval, being satisfied that those limitations were being addressed.

Features of the Borescope Inspection

- The Borescope Inspections were not carried out in accordance with the procedures detailed in the manufacturers Task Cards and the Aircraft Maintenance Manual. Specifically:-

The two HP rotor drive covers, one on each engine, had not been refitted after the Borescope Inspections.

A post inspection ground idle engine tests had not been conducted.

The entry in the aircraft Technical Log, relating to Borescope Inspections, had wrongly been signed as having been completed in accordance with the Aircraft Maintenance Manual.

- Work originally planned for Line, transferred to base.
- Line and Base staff shortages including the absence of three Base supervisors.
- Minimal preplanned paperwork consistent with Line Maintenance.
- In order to retain his Borescope authorization Base Controller performed the inspections.
- A/C was remote and took the Base Controller away from the location of his other duties.
- The Line Engineer gave a verbal handover to the Base Maintenance Controller.
- Inadequate reference to Maintenance Manual.
- Use of an unapproved reference source.
- Poor lighting conditions.
- Many interruptions.
- Early hours of morning - Circadian lows.
- No post inspection engine runs - a deviation from the Maintenance Manual.
- 9 previous occurrences.
- Staff had regularly completed Borescope Inspections in a non procedural manner, failing to replace the HP rotor drive cover O-rings or to conduct an idle engine run, both specifically required by the Aircraft Maintenance Manual.
- The operator's Quality Assurance system had not identified frequent deviations from a procedural approach and failure to observe the requirements of the AMM over a considerable period of time.
- The regulator’s monitoring system had been ineffective in identifying and making the operator correct the same procedural lapses.

Common Features:-

- Night shift.- engineers operating at their Circadian lows. Most Maintenance at night.
- Supervisors tackling long duration, hands -on involved tasks.
- Interruptions
- Failure to use the Maintenance Manual - IPC
- Confusing -misleading difficult manuals
- Shift handovers - poor briefing - lack of comprehensive stage sheets
- Time pressures
- Limited preplanning paperwork, equipment, spares
- Staff shortages
- Determination to cope with all challenges.

Although many ingredients are demonstrated to have come together to create these incidents, what if some are there all the time?

CONCLUSIONS

The only object of identifying the causal factors and contributing features of an accident/incident for the government investigator is accident/incident prevention. This means that once a cause has been identified it must be accepted by the industry and change implemented to avoid a repeat. If nothing changes the most elegant of investigations is as nought, a waste of time and effort.

The first hurdle to the implementation of change to address a human factor cause is acceptance of the finding that some one or some organization failed to perform adequately. This involves one or more individuals, a flight crew, a design team, a maintenance crew, a management accepting that their performance on the day or over a period of time, perhaps for reasons outside of their control, fell below par.

If the subject of the Investigation is an incident without injury or damage there is generally more of a willingness on the part of all parties to the investigation to accept the findings. When a human factor cause is cited, the burden of coming to terms with the realisation that, as an individual or an organization, performance has been sub-standard can usually be accommodated, even if with some discomfort. None of us finds it easy to accommodate responsibility for our actions when they lead to an incident but much worse an accident. So incidents offer us a route to human factors in engineering.

Even when the investigation is of an incident, my personal experience is that the collection and analysis of evidence to produce an acceptable conclusion is very Challenging. Making the connection between individual performance on a specific task to a more general conclusion about the personnel or the organization and its culture is a difficult step. Considering the organizations performance within the context of the Regulations and the role of the Regulator in monitoring compliance, is a further step away from the individual occurrence. However, if the causes are systemic these links are core to understanding the real causal factors and making effective changes.

In the investigation of human factors the evidence is often circumstantial, subjective and sometimes easy to collect but often impossible to corroborate. Should Investigators, pursuing such an investigation, be constrained to achieve proof of their findings to meet

some legal definition? Can Human Factors be dissected and analyzed in such a way to provide such proof in most circumstances? I believe not.

I believe that the incidents cited in this paper, along with others that I have investigated, indicate that many of the factors which came together to contribute to their causes are with us most, if not all of the time. The development of maintenance practices over several generations of aircraft types has delivered us to where we are today. Are the processes appropriate to today's high technology aircraft which we operate in a high pressure, fiercely competitive operational climate? The volume of material that the engineer is required to have available and accessible to perform his task on the aircraft is enormous - is it really presented in such a way that he can be aware of all of its significance? Is information in a large number of volumes on the shelf or on a micro-film reader readily available and usable by the engineer trying to meet tight operational deadlines? In moving from Quality Control to Quality Assurance in some cases are we monitoring the administration of the task and not the quality of the engineering product? Have commercial pressures resulted in minimal staff allocations to the task, allocations which rarely materialize due to absences for leave, sickness or training?

Up to the time of the above incidents all of the individuals involved were considered to be well qualified, competent, reliable employees selected for management roles. Immediately afterwards they were shocked at what had happened and would be condemned by many; but how had they suddenly changed during the few hours of the task? The answer is that they had not! The individual must shoulder some responsibility but the real causal factors are systemic and do not stop at the individual but reside within the culture of the organization. An organization approved by the Regulator.

The significance of incidents as rehearsals for catastrophic accidents is sometimes recognized all too late; these three incidents have identified a wide range of common features conspiring to undermine the pursuit of quality in aircraft maintenance. What this indicate is that there is a need for an independent review of the way we regulate, conduct and deliver assured quality in aircraft maintenance.

I believe that incident investigation is the route to human factors in engineering. This route and these investigations are already telling us something. Are we going to listen, are we going to act?

REFERENCES

1. Aircraft Accident Report 1/92. Report on the accident to BAC One-Eleven, G-BJRT over Didcot, Oxfordshire on 10 June 1990. HMSO

2. Aircraft Accident Report 2/95. Report on the incident to Airbus A320-212, G-KMAM at London Gatwick Airport on 26 August 1993. HMSO

3. Aircraft Accident Report 3/96. Report on the incident to Boeing 737-400, G-OBMM overhead Daventry on 23 February 1995. HMSO